NEOTROPICAL BIOLOGY AND CONSERVATION

Neotropical Biology and Conservation
15(4): 427–445 (2020)
doi: 10.3897/neotropical.15.e52905

RESEARCH ARTICLE

Main trends and gaps in studies for bird conservation in the Pantanal wetland

Angélica Vilas Boas da Frota[1], Breno Dias Vitorino[1], Josué Ribeiro da Silva Nunes[1], Carolina Joana da Silva[1]

1 *Programa de Pós-graduação stricto sensu em Ciências Ambientais (PPGCA), Centro de Pesquisa em Limnologia, Biodiversidade e Etnobiologia do Pantanal (CELBE), Universidade do Estado de Mato Grosso (UNEMAT – Cáceres), Cáceres, Mato Grosso, Brazil*

Corresponding author: Angélica Vilas Boas da Frota (angelicafrotaa@gmail.com)

Academic editor: A. M. Leal-Zanchet | Received 5 April 2020 | Accepted 18 September 2020 | Published 9 October 2020

Citation: Frota AVB, Vitorino BD, Nunes JRS, da Silva CJ (2020) Main trends and gaps in studies for bird conservation in the Pantanal wetland. Neotropical Biology and Conservation 15(4): 427–445. https://doi.org/10.3897/neotropical.15.e52905

Abstract

Birds are considered one of the most well-known groups of animals in the Pantanal, playing an important ecological role in wetland ecosystems. Our aim was to identify the main themes and gaps in current knowledge of these birds, considering thirty years of scientific research to direct future studies. We performed a scientometric analysis based on five platforms with the search words "Aves" and "Pantanal" as well as "Bird" and "Pantanal". We identified 145 scientific studies, with themes of ecology (64), conservation (23), health (17), fauna (15), genetics (12), geographic distribution (7), and environmental education (7). The number of publications has increased significantly over the years. However, the focus is predominantly on certain Pantanal regions, such as the municipalities of Corumbá in Mato Grosso do Sul state and Poconé in Mato Grosso state. *Anodorhynchus hyacinthinus* and *Mycteria americana* are among the species with the largest number of studies in the Pantanal, with 12 and 11 papers, respectively. We highlighted the need for new studies in regions such as the north-west and themes such as threatened species and ecosystem services. Integrated knowledge and interdisciplinary approaches can be useful in strategic decision-making and more effective for bird conservation in wetlands.

Keywords

avian, biodiversity, floodplain, review, scientific knowledge, waterbirds

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PENSOFT

Introduction

The Pantanal wetland ecosystem represents a heterogeneous and complex landscape (Miranda et al. 2018). It is located in the Upper Paraguay Basin, the center of the Paraguay watershed in South America. This ecosystem is characterized by the existence of a single-mode and predictable flood pulse water regime. Pantanal biodiversity is adapted to the ecological and hydrological processes of this floodplain (Junk et al. 1989; Junk and Da Silva 1996). A total of 582 species of birds have been recorded in the various habitats of the Pantanal (Nunes 2011). This wetland is also a route and concentration zone of migratory birds (Oliveira et al. 2016a). However, both the plateau and floodplain of the Pantanal have been threatened by unsustainable activities that may impact the hydrological system and landscape in multiple ways (Tomas et al. 2019).

Birds play an important ecological role with their movement of energy and nutrients in wetland ecosystems (Green and Elmberg 2013) and can be excellent indicators of environmental changes in the floodplain (Alho 2008). In the Pantanal wetland, birds are considered one of the most well-known biological groups (Junk et al. 2006). However, the birds' responses to change in their habitats' use are also poorly understood (Pinho and Marini, 2012), making it difficult to understand their environmental functions and interactions in wetland ecosystems (Green and Elmberg 2013).

Analyzing scientific production in terms of environmental themes is recognized as an important conservation tool (Nabout et al. 2012), producing a detailed understanding of different areas of knowledge (Teodoro et al. 2020). In addition, it enables the identification of researchers' preferences for certain areas, study locations, definition of concepts and applications, main trends, and gaps regarding the themes considered (Kullenberg and Kasperowski 2016; Freitas and Mantovani 2018; Hannibal et al. 2019; Baldiviezo et al. 2019).

Scientific knowledge regarding the birds of the Pantanal can positively contribute to the conservation of biodiversity and macrohabitats in this floodplain. This review investigates the main themes and gaps in scientific research conducted on birds in the Pantanal wetland over the last 30 years with the aim of providing a useful tool to direct future studies of wetland birds. Here we explore whether there has been an increase in the production of scientific literature during this period, and present an overview of what aspects of birds in the Pantanal have been studied.

Methods

Scientometric research is considered to be interdisciplinary as it uses methods from the natural and social sciences (Van Raan, 1997). The scientometric analysis adopted in the present study followed the methodological process applied by many

other researches (e.g. Espécie et al. 2019; Baldiviezo et al. 2019; Marroco et al. 2019; Teodoro et al. 2020), with searches for terms in databases, then unrelated studies being manually excluded from the search results, and finally categorization being performed. So, we measured and analyzed the scientific literature in five database platforms: Scielo, Scopus, Web of Science, Science Direct, and Google Scholar. The search terms used were combinations of "Aves" and "Pantanal" as well as "Bird" and "Pantanal". We considered any studies indexed in the databases that showed the cited terms in the title, abstract, and / or key-words. However, in Google Scholar only papers where the terms occurred within the title were considered, due to limitations in searching the database. The search was performed in January 2020.

The type of literature considered included papers, scientific notes/short communications, and technical-scientific documents with an International Standard Book Number (ISBN) or International Standard Serial Number (ISSN). A limit was set for publication dates between 1989 and 2019, taking into account when the flood pulse concept was applied to the Pantanal (Junk et al. 1989; Junk and Da Silva 1996). The material found was managed in a data sheet with the following indicators: authorship, institution, title, year of publication, and journal.

The major database was considered to be the one presenting the largest number of indexed documents. To evaluate the temporal trend in the number of publications, a simple logistic regression was performed analysing the number of documents in relation to year of publication. This analysis was performed in the *R* programming environment (R Development Core Team 2019) using the "ggplot2" package (Wickham 2016). We considered values of $p \leq 0.05$ to be significant.

The research core and partnerships between the authors and/or co-authors were identified by a cluster analysis. Through network interactions we determined the main research nucleus from the number of clusters and partnership links. Authors who produced two or more documents were considered for analysis. This analysis and the network maps were elaborated in the software VOSviewer (Van Eck and Waltman 2010). Subsequently, we showed some authors, affiliations, and journals.

The central themes of the studies were defined by reading to identify the main subject areas and approaches. Then, we classified papers by study location and *taxa* studied. We used QGIS v. 3.10.5 (QGIS.org 2020) to draw a map with points for each study site in the Pantanal wetland in order to identify local gaps. Inaccurate locations, locations that were not available, or were outside of the Upper Paraguay Basin and Brazilian territory, are not shown on the map, but were considered in the analysis to find the proportion of the total area studied. We used the *Agência Nacional das Águas* (2019) and *Instituto Brasileiro de Geografia e Estatística* (2019) for the cartographic base. The geodetic datum selected was SIRGAS 2000 with geographic coordinate system projection. All documents found in the search were data pre-selected in order to remove duplicate information between the bases and/or scope outside of the thematic context.

Results

Sciometric analysis

We found a total of 441 documents about birds in the Pantanal published between the years 1989 and 2019. Following data selection 296 duplicate documents and/or documents outside the scope of our search were removed. Then, 145 documents were evaluated: 133 were scientific articles, six were scientific notes/short communications, five were technical-scientific documents and one was a book chapter (Suppl. material 1). Scopus (44%) and Web of Science (29%) were identified as the major databases because they contained the largest number of documents available (Fig. 1).

There was a significant positive correlation ($R^2 = 0.64$; $p < 0.001$) between the number of publications and year (Fig. 2). The last 10 years were the most productive and the years with the highest number of publications were 2008 (11) and 2017 (16). The period between 1989 and 2001 had the lowest number of published scientific studies in this field.

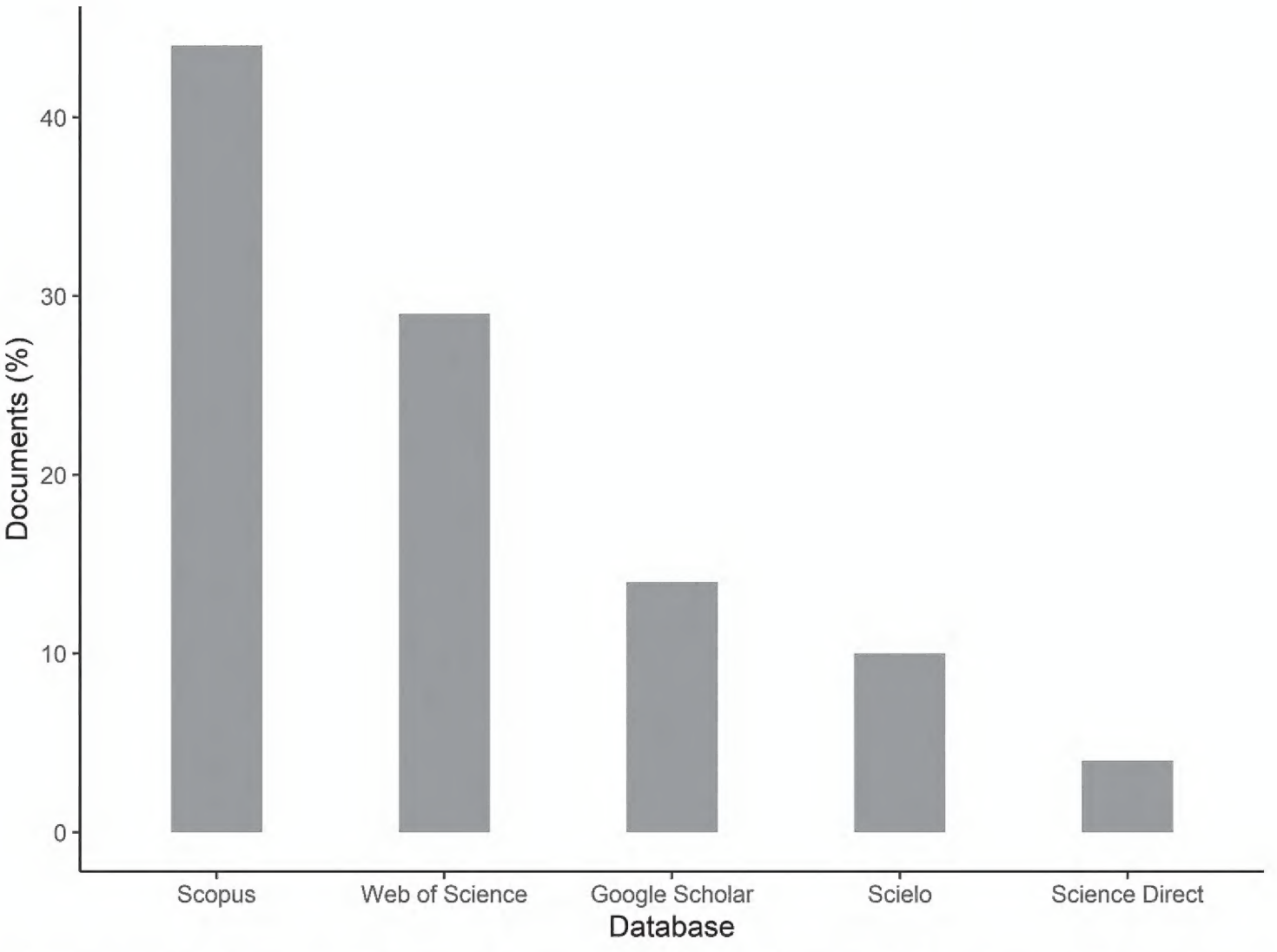

Figure 1. Proportion of publications (%) between 1989 and 2019 with the terms "Aves", "Bird", and "Pantanal" in the title, abstract and/or key-words found using the database platforms Scielo, Scopus, Web of Science, or ScienceDirect, and from Google Scholar with these terms only in the title. The search was conducted in January 2020.

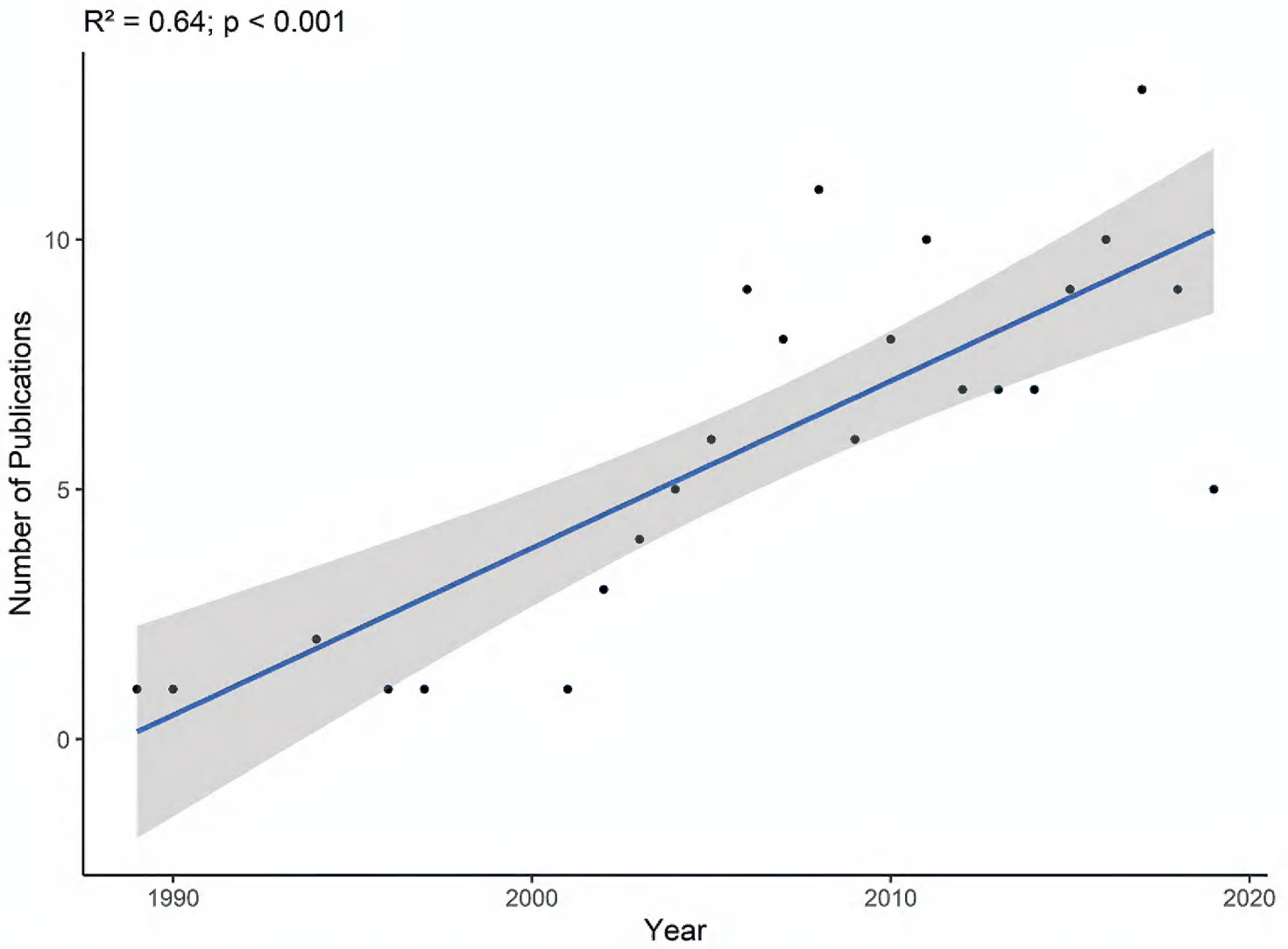

Figure 2. Positive trend ($R^2 = 0.64$; $p < 0.001$) in the number of publications by year, showing an increase from 1989 to 2019. Data from the literature review with the terms "Aves", "Bird", and "Pantanal" featured in the title, abstract, and/or keywords found on the platforms Scielo, Scopus, Web of Science, or ScienceDirect, and on Google Scholar with words found in the title only. The search was conducted in January 2020.

The research nucleus comprised 67 authors and co-authors, of the total 342 researchers in the network analysis. We found 12 clusters with 135 links. Some core authors that we noted in the connections were: Pinho J.B., Del Lama S.N., Tomas W.M., Nunes A.P., and Guedes N.M.R. Among the authors, we noted that Yamashita C. was one of the earliest in the field and Silva F.M. was one of the latest (Fig. 3A, B).

Of the 10 authors and/or co-authors with the highest number of publications in the field, 60% were linked to institutions located in the Pantanal region, such as Universidade Federal de Mato Grosso (UFMT), Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Universidade Federal do Mato Grosso do Sul (UFMS), and Universidade para o Desenvolvimento do Estado e da Região do Pantanal (UNIDERP) (Table 1).

Among the 75 different journals found in the search, those with the highest number of publications were related to ornithology, zoology, and biodiversity conservation (Table 2). Ornithology Research (formerly known as the Brazilian Journal of Ornithology and Ararajuba) stood out with 21 publications, followed by the Brazilian Journal of Biology (15), Embrapa (6), and Atualidades Ornitológicas (5).

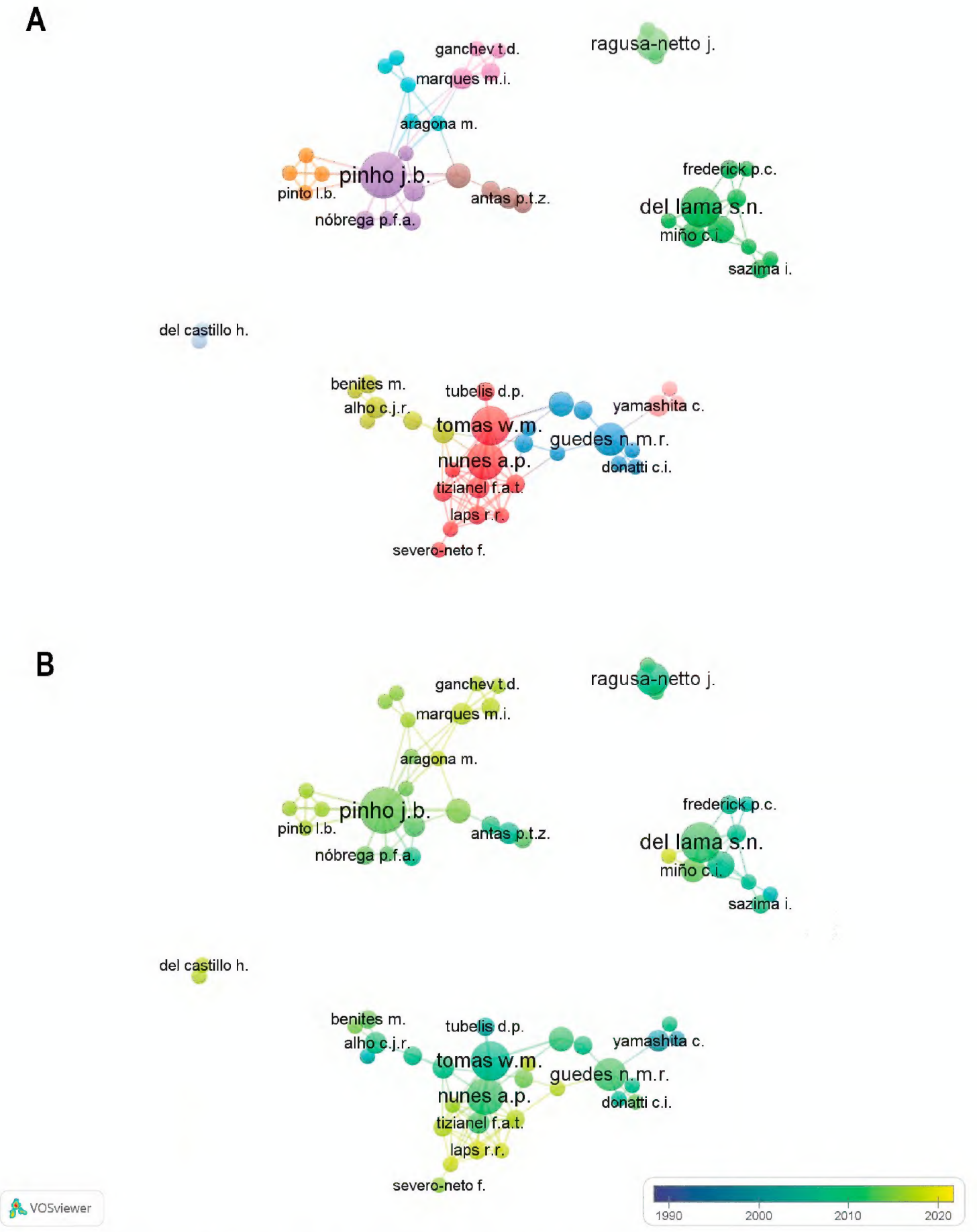

Figure 3. **A.** Network map cluster and **B.** overlay, showing scientometric data in relation to core researchers and partnerships between authors with 12 clusters and 135 links. Researcher clusters are represented by different colors. Each author and/or co-author is represented by a circle with a size corresponding to his/her number of publications, so the bigger the circle, the more co-productions were retrieved. Connections between authors and/or co-authors are represented by lines. To avoid overlapping labels (researcher name), some have not been displayed in their respective circles. The search considered papers published from 1989 to 2019, featuring the terms "Aves", "Bird", and "Pantanal" in the title, abstract and/or keywords found on the platforms Scielo, Scopus, Web of Science, ScienceDirect, and on Google Scholar with these terms in the title only. The search was conducted in January 2020.

Table 1. Some authors and institutions with the highest number of publications with the terms "Aves", "Bird", and "Pantanal" featured in the title, abstract and/or keywords found on the platforms Scielo, Scopus, Web of Science, or ScienceDirect, and on Google Scholar with these terms in the title only. The search considered the period from 1989 to 2019 and was conducted in January 2020.

Order	Authors	Publications	Institution
1°	Pinho J.B.	17	Universidade Federal do Mato Grosso (UFMT)
2°	Del Lama S.N.	13	Universidade Federal de São Carlos (UFSCar)
3°	Tomas W.M.	12	Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
4°	Nunes A.P.	11	Bioma Meio Ambiente Ltda
5°	Neves N.M.R.	9	Universidade para o Desenvolvimento do Estado e da Região do Pantanal (UNIDERP)
6°	Ragusa-Netto J.	9	Universidade Federal do Mato Grosso do Sul (UFMS)
7°	Lopes I.F.	6	Universidade Federal de São João Del Rei (UFSJ)
8°	Miño C.I.	5	Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)
9°	Mourão G.M.	5	Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
10°	Marini M.Â.	5	Universidade de Brasília (UnB)

Table 2. Some journals with the largest number of publications between 1989 and 2019 with the terms "Aves", "Bird", and "Pantanal" featured in the title, abstract and/or keywords found on the platforms Scielo, Scopus, Web of Science, or ScienceDirect, and on Google Scholar with these terms in the title only. The search was conducted in January 2020.

Order	Journal	Number of publications
1°	Ornithology Research (Brazilian Journal of Ornithology / Ararajuba)	21
2°	Brazilian Journal of Biology	15
3°	Embrapa	6
4°	Atualidades Ornitológicas	5
5°	Biota Neotropica	4
6°	Bird Conservation International	4
7°	Check List	4
8°	Papéis Avulsos de Zoologia	4
9°	Ornitologia Neotropical	3
10°	Plos One	3

Main approaches

We identified seven main themes for studying Pantanal´s birds in the publications: ecology (64), conservation (23), health (17), fauna (15), genetics (12), geographic distribution (7), and environmental education (7) (Fig. 4). Among the thematic areas, it was possible to identify different applications, such as "Ecology", which comprised studies associated with interactions (Sazima et al. 2001; Galetti and Guimarães, 2004; Ragusa-Netto 2007; Almeida and Anjos-Silva 2015; Sebastián-González et al. 2017); reproductive biology (Carrara et al. 2007; Mourão et al. 2011; Pinho and Marini 2014; Schuchmann et al. 2018), habitat use (Figueira et al. 2006; Yabe et al. 2010; Donatelli et al. 2017), migration (Del Lama et al. 2015; Pinho et al. 2017), diet (Gaiotti and

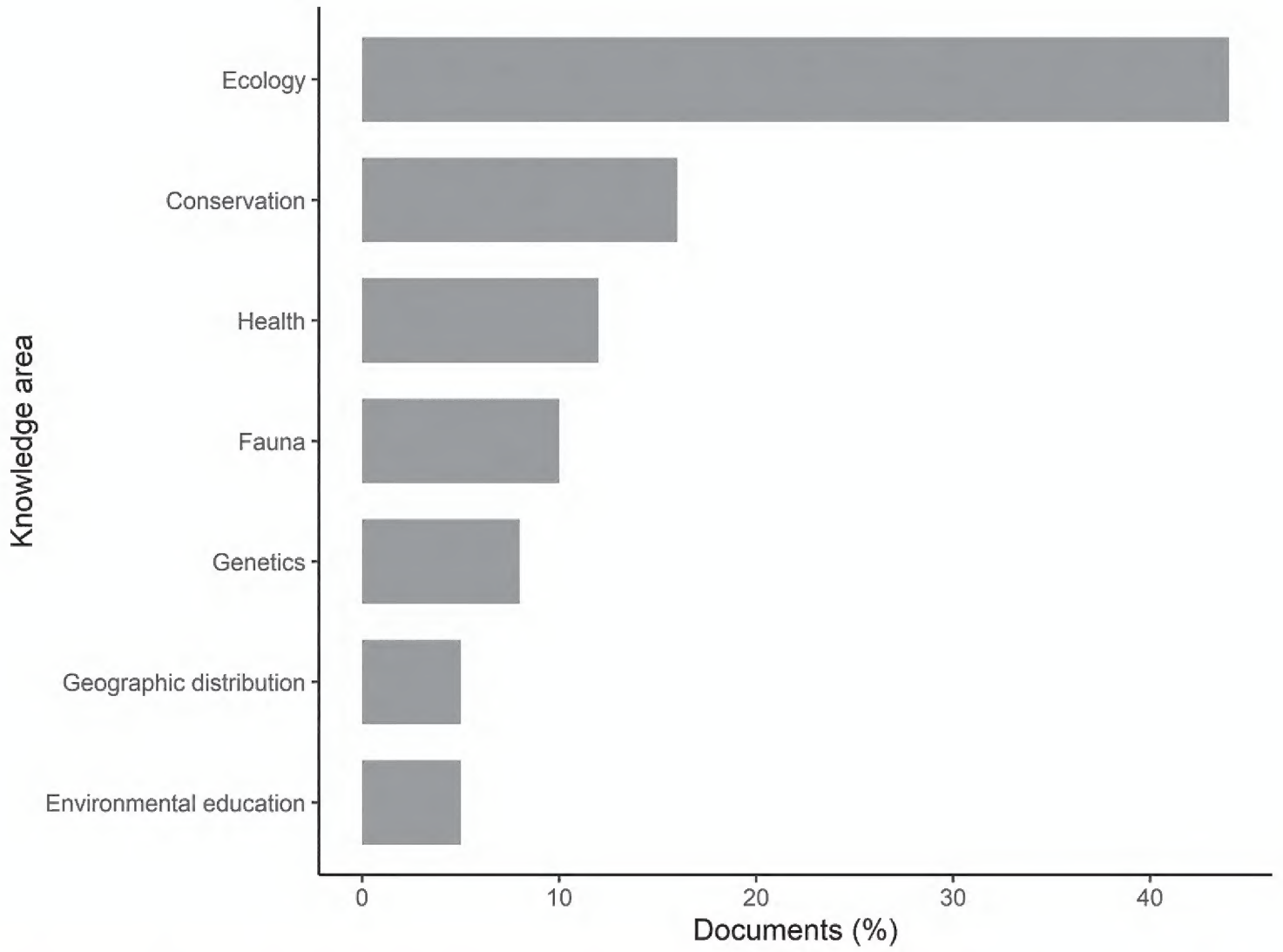

Figure 4. Main topics of publications between 1989 and 2019 with the terms "Aves", "Bird", and "Pantanal" featured in the title, abstract and/or keywords found on the platforms Scielo, Scopus, Web of Science, or ScienceDirect, and on Google Scholar with these terms in the title only.

Pinho 2013; Heming and Jezuíno 2016), and animal behavior (Ubaid 2011; Tortato and Bonanomi 2012; Almeida et al. 2014). These studies generally evaluated a single species, except for habitat use studies that also considered the bird community.

In the area of "conservation", factors related to human impact were discussed as one of the main threats, unmonitored tourist activities, for example, which disturb nesting colonies (Bouton and Frederick 2003; Bouton et al. 2006) and habitat change and unexpected changes in water fluctuations in the Paraguay Hydrographic Region (Harris et al. 2005; Alho 2008). Some studies mentioned possible conservation measures, such as the creation or expansion of protected areas in wetlands where threatened species are found (Nunes et al. 2006), greater understanding of species' movements (Nunes and Tomas 2004), and project continuity (Guedes 2004).

Studies into the health status of birds, such as the impact of heavy metal contamination (Del Lama et al. 2011; Marchesi et al. 2015), parasites (Allgayer et al. 2013; Ramos et al. 2015), and infections (Raso et al. 2006; Chahad-Ehlers et al. 2018) were included under the study theme of "health".

Studies included under the theme of "fauna" comprised surveys with commented lists, revisions and additions to the Pantanal taxa, or more specific locations (Tubelis and Tomas, 2003; Nunes 2011; Ubaid and Antas, 2013; Pinho et al. 2016). In relation to articles considered under the theme of "distribution", we noted the re-

corded range expansion of *Oxyura vittata* (Philippi, 1860) (Severo-Neto et al. 2017) and documented records with reproductive data for two species of the Accipitridae family occurring in the Pantanal: *Urubitinga coronata* (Vieillot, 1817) and *Harpia harpyja* (Linnaeus, 1758) (Chiaravalloti et al. 2009; Ubaid et al. 2011).

Studies with the theme of "genetics" focused mainly on common species of the Pantanal region and species that are distributed in other locations in Brazil and in the world. Although the population of *Anodorhynchus hyacinthinus* (Latham, 1790) in the Pantanal is increasing, the genetic structure observed for this species shows low variability, emphasizing the need for its conservation in other locations too (Faria et al. 2008). Other species that demonstrate low levels of gene flow among populations are, for instance, *Mycteria americana* Linnaeus, 1758, *Jabiru mycteria* (Lichtenstein, 1819), and *Platalea ajaja* Linnaeus, 1758 (Lopes et al. 2006, 2011, 2013).

Studies in the area of "environmental education" mainly discussed birdwatching as a sustainable tourism activity. Some studies assessed the viability of this enterprise in the opinion of the tourist and the infrastructure available in the Pantanal southern region (Pivatto et al. 2007; Pivatto and Sabino 2007). Already in the southern region, leisure activities stand out as an efficient means of science education (Nogueira et al. 2015).

A total of 379 locations were studied in 30 municipalities in the Upper Paraguay Basin (Fig. 5). The most studied place was the Pantanal region in the state of Mato Grosso do Sul (62%), with research conducted mainly in the municipalities of

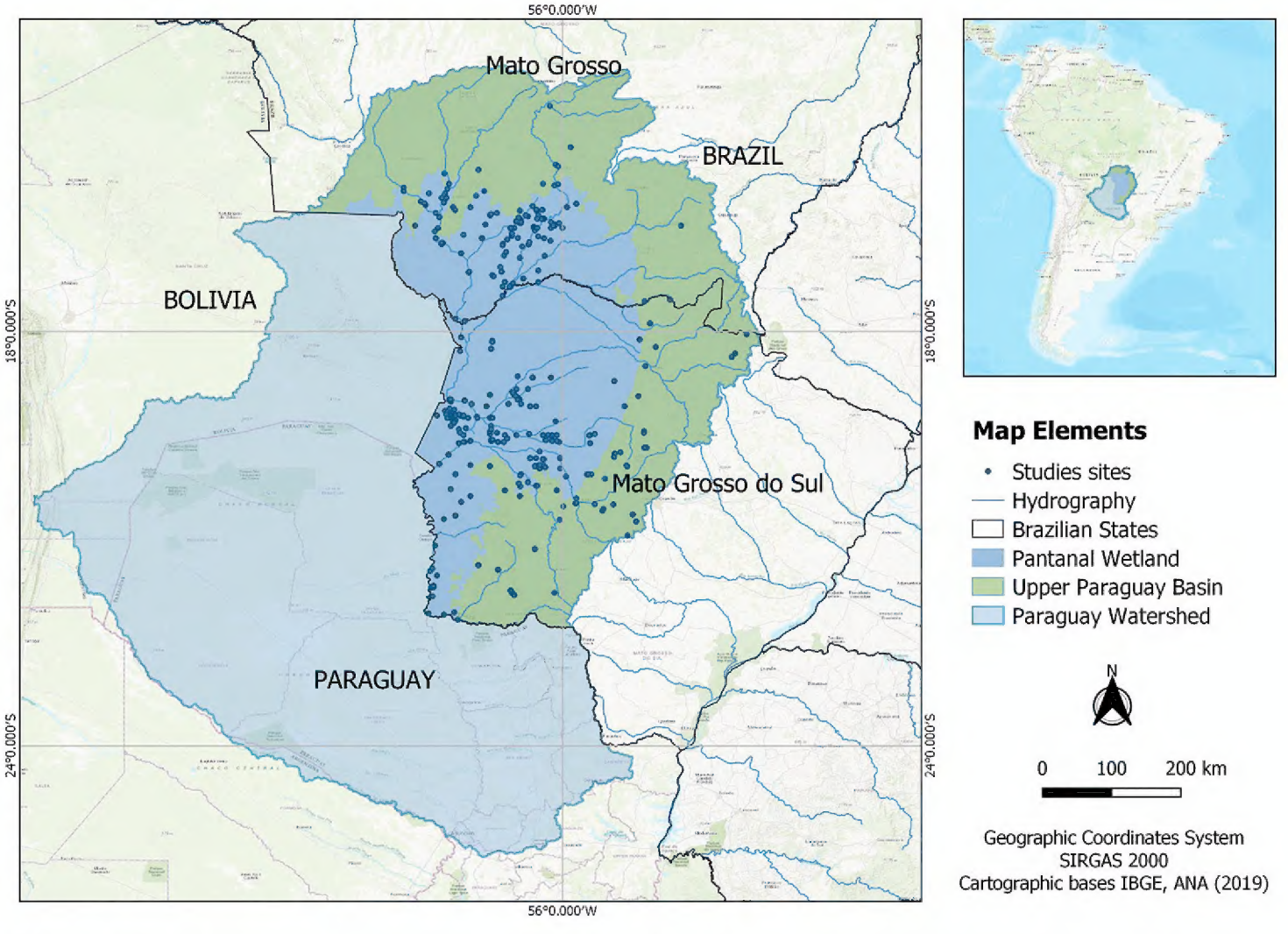

Figure 5. Publications by study site in the Pantanal wetland, between 1989 and 2019, with the terms "Aves", "Bird", and "Pantanal" featured in the title, abstract and/or keywords found on platforms Scielo, Scopus, Web of Science, and ScienceDirect, and on Google Scholar with these terms in the title only.

Corumbá (28%), Aquidauana (12%), Miranda (5%), and Porto Murtinho (4%). In Mato Grosso State (38%), research was conducted primarily in the municipalities of Poconé (20%), Cáceres (7%), Barão de Melgaço (6%), and Nossa Senhora do Livramento (3%). More studies were conducted in the Brazilian Pantanal (97%) than in the Pantanal outside Brazil (3%).

Studies of the bird community (51), and Pantanal biodiversity (16) predominated. However, there were also a large number of studies about the health status, genetic structure, and reproductive aspects of species such as *Anodorhynchus hyacinthinus* (Latham, 1790) (12), *Mycteria americana* Linnaeus, 1758 (11), and *Platalea ajaja* Linnaeus, 1758 (4).

Discussion

The number of documents found in this study demonstrates that scientific knowledge regarding birds in the Pantanal has increased over the years. This advance in scientific research shows that there is a support base for new directions and the maintenance of priority studies. In addition, the demand for scientific research may be related to local needs, given the recognition of environmental problems and conservation initiatives (Harris et al. 2005).

Flood pulse is an important process contributing to the biodiversity of the Pantanal (Junk et al. 1989; Junk and Da Silva 1996), and understanding this process can support bird ecology and conservation studies, which were the most common approaches to research. For example, studies considered hydrological factors to be a driver for the reproduction, habitat use, and migration of bird species (Pinho et al. 2009; Nóbrega and Pinho 2010; Donatelli et al. 2014; Schuchmann et al. 2018).

Although the Pantanal supports more species than other wetlands in the world (Nunes 2011), we observed that advanced studies, such as those of genetic evaluation and health status, are still limited to birds that are widely distributed and have well-known biology. However, these assessments demonstrated that further efforts are needed to protect wetland habitats to maintain genetic variability and preserve the health of animal species.

In addition, we would highlight the relevance of projects for the conservation of endangered species which have been successful, such as those concerned with the conservation of *A. hyacinthinus*. Several studies on the maintenance of its population in the Pantanal have been carried out, generating important information about the ecology, distribution, health, and well-being of these animals (Suppl. material 1).

Birdwatching tourism can be a conservation partner in the Pantanal due to the high environmental heterogeneity required by the characteristic birds of wetlands and adjacent biomes, as mentioned in some lists, for instance Nunes (2011) and Nunes et al. (2018). Birdwatching activity is growing in Brazil, and measurement of the disturbance this causes and control of tourist visits can contribute to continuing environmental education and the management of sustainable tourism (Bouton and Frederick 2003; Bouton et al. 2006).

Most of the inventories, and studies of ecological aspects and on bird conservation with sampling effort are confined to particular regions, generally those that are easy to access or infrastructure to support research (see the infrastructures in Tomas et al. 2019). Thereby, conducting systematic sampling on the floodplain can also be considered a challenge for researchers. According to Oliveira et al. (2016b), access route density is lower in the Pantanal than in other environments, and the implementation of studies in regions with lower sampling effort should be more effective in extending knowledge of the species present. The location of previous studies showed that the sites include support bases of farms or lodges (e.g. Bouton et al. 2006; Donatelli et al. 2017), protected areas (e.g. Barbosa et al. 2014; Ubaid and Antas 2013) and research sites (Signor and Pinho, 2011; Ubaid and Antas 2013). This fact supports the idea that investment in research infrastructure, specialized personnel, and project management is needed to further understand and conserve biodiversity.

We would draw attention to gaps in knowledge regarding birds in certain locations in the Pantanal such as the north-west, north-east, the western border, south-west, and central regions. These regions cover large territories with marked structural complexity, typical species are from the wetlands and savanna of the Paraguay river (Frota et al 2020), as well as influences coming from the Chiquitano Dry Forest, Amazonia (Nunes et al 2018), Gran Chaco (Benites et al 2017), and the plain-plateau of the Taquari-Correntes River basin. However, long-term studies should be performed to clarify the biology of species (Nunes et al 2018; Frota et al. 2020) and advance scientific knowledge. The Pantanal has been widely threatened by the activities of agribusiness and mining, navigation, climate changes, and increases in the occurrence of fire, resulting in high-impact landscape changes and consequent effects on biodiversity (Tomas et al. 2019). Some of the studies found in our search were carried out on the Pantanal Plateau (i.e. Vitorino et al. 2018), which is also threatened by these activities. Studies aimed at the conservation of the Pantanal should also direct their efforts at protecting the plateau and supporting the Paraguay watershed. Many of the headwaters and tributaries' rivers of the floodplain are in this region and they have been widely devastated by deforestation, the building of hydroelectric power plants, and environmental contamination.

Further, we observed that there was low connectivity between groups of researchers and we would encourage authors to form partnerships and institutions to share information. Moreover, we highlight the following important themes that should be further explored in the Pantanal: studies that evaluate the dynamics of species using floodplain habitats and the effect of landscape changes due to hydrological periods (Figueira et al. 2011; Pinho and Marini 2012; Donatelli et al. 2017); studies of the functional roles and ecological interactions of frugivory, dispersal, pollination, predation, and population control, all of which are considered important ecosystem functions of bird species (Whelan et al. 2008; Green and Elmberg 2013); environmental valuation; research into contamination levels to promote greater responsibility and control in the use of chemicals (Del Lama et al. 2011; Marchesi et al. 2015); monitoring the genetic structure of breeding colonies; research to identify and prioritize threatened species; studies to increase our understanding of migra-

tory movements; and evaluation of the perspective of the social actors involved in the use and conservation of biodiversity (Bouton and Frederick 2003).

Final considerations

It is vital to expand scientific knowledge of the wetland birds in an ecosystem that is sensitive to environmental changes, such as the Paraguay watershed. Given the local, regional, and global threats to the Pantanal's biodiversity, we recommend studies of the avifauna in regions and through themes that are still poorly explored, long-term studies on species and their relationships with wetlands. In addition, greater efforts to protect threatened habitats and species, combined with integrated knowledge of ecosystems and more interdisciplinary approaches, may result in more effective decision-making in the conservation of wetland birds.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finace Code 001, and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq): AVBF and BDV received a scholarship from FAPEMAT / CAPES 007/2018, and CJS received a research fellowship from CNPq; We also thank CNPq for support in Long-Term Ecological Research (LTER) Pantanal "Ecological Dynamics of the Upper Paraguay River" (no. 441563/2016-3), contribution number 5 for this project; the FAPEMAT for support in CORE project "Ecological, Economics and Cultural Corridor of the Paraguay River" (no. 0308817/2017), contribution number 3; the Programa de Pós-graduação em Ciências Ambientais of Universidade do Estado de Mato Grosso, Cáceres and Centro de Pesquisa em Limnologia, Biodiversidade e Etnobiologia do Pantanal for support; teachers Sandro Sguarezi and Liliane Alcântara for their encouragement towards accomplishing this research; and Alessandro Pacheco Nunes for reviewing the draft manuscript.

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Supplementary material 1

List of scientific documents published among 1989 and 2019 years about birds in the Pantanal wetland

Authors: Angélica Vilas Boas da Frota, Breno Dias Vitorino, Josué Ribeiro da Silva Nunes, Carolina Joana da Silva

Data type: reference data

Explanation note: Documents with the terms "Aves", "Bird", and "Pantanal" in the title, abstract and/or key-words found on platforms database Scielo, Scopus, Web of Science, and Science direct, and Google Scholar with the terms only in title. The search was conducted on January 2020.

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Link: https://doi.org/10.3897/neotropical.15.e52905.suppl1